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Revision Memo

06/04	This revision updates the list of dispersion models currently used within EMRE, corrects typographical errors within various texts, and updates Table 1 , Representative Ambient Air Quality Standards.
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1 SCOPE

This section is about calculating concentrations of non-reactive pollutants emitted from typical process industry sources for comparison to appropriate ambient and work-place criteria. It describes methods and computer programs that can be used. Some methods are simple; many are very complex and require use of specialized computer programs. Some emissions are lighter than air and others are heavier than air; they are modeled very differently. Emission sources include conventional flue gas stacks from fired heaters, boilers, and gas turbines; flares; process vents; tanks; fugitive emissions; accidental releases of gases; and spills of volatile liquids. Emissions may be continuous, short-duration, or intermittent. Most methods apply to flat terrain and are used to predict hourly to annual ambient ground-level-concentrations (glcs) for distances out to about 10 – 50 kilometers (~6 – 30 miles). For calculation purposes, pollutants are assumed to disperse as gases.

Here, the overall approach is to describe the basic method and then to provide guidance to select computer programs for air dispersion calculations. First, several necessary definitions are provided for general terms used in air pollution. Then, a brief overview of atmospheric meteorology is given. Finally, the basic calculation methods are presented for estimating plume rise; building and stack tip downwash; ambient, ground level concentrations for conventional flue gas stacks and flares; and the conversion of maximum ground-level-concentrations from one averaging-time to another.

For routine calculations, computer programs are normally used. Therefore, guidance is provided for selecting proprietary ExxonMobil Engineering and selective public domain computer programs that can be used for either screening-quality or more rigorous air dispersion analyses. The screening-quality programs essentially computerize the basic dispersion calculation method for discrete meteorological conditions of emissions from a single stack. These results are intended to be more conservative (higher concentrations of pollutants) than those from the more rigorous tools. The rigorous computer programs have many capabilities to more realistically simulate the actual emissions sources, meteorological conditions, and receptor characteristics of the particular facility being analyzed. However, significantly more input data and professional time are required to use these programs. The more rigorous or refined programs are used widely in air quality permitting. Beyond permitting, dispersion results from appropriate computer programs are used in chronic and acute community health and risk assessment studies for toxic and flammable substances. Typically, advanced knowledge and expertise is required to conduct these studies. This expertise may be obtained from ExxonMobil Engineering's Environmental Engineering Section, selected individuals in the Safety, Civil, and Marine Section, or a qualified outside air dispersion modeling consultant.

♦ Predicted pollutant concentrations using air dispersion models can be considered an estimate of the pollutant concentration that would be measured at a specified location and time after release. The agreement between calculated pollutant concentrations and actual ambient levels depends upon many factors, including:

- Model used (e.g., screening vs. refined)
- Dynamic variability in meteorological conditions, including atmospheric stability (e.g., measured meteorological data or average stability class) and wind speed
- Terrain variability and urban structures
- Actual vs. calculated plume rise
- Uncertainty in the emissions rate and source compositions
- Type of pollutant and concentration thresholds (e.g., odorant vs. toxic)
- Type of source (area, volume, or point)
- Assumed averaging time

Because these and other factors contribute to differences between calculated and actual ambient concentrations, it is important that persons familiar with ambient air quality impact assessments review calculation methodologies and results.

♦ **Note that metric units are provided as the primary convention** for this section consistent with universally accepted practice for Air Dispersion Calculations. Customary units are provided within brackets, i.e., opposite to convention adopted for the DPs.

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3 BACKGROUND

Throughout the world, dispersion calculation methods are used to quantify the impact of pollutant emissions on the environment. For example, regulatory agencies rely on these methods for permitting new and modified industrial facilities. Dispersion calculation methods offer the only technique available to forecast the impact of these new operations on air quality. Calculated impacts are compared to ambient air quality standards that have been promulgated by worldwide regulatory agencies ([Table 1](#)). More recently, regulations have been promulgated that require dispersion calculations in risk analyses of chronic and acute hazardous substances emitting from industrial facilities.

As the United States (US) Environmental Protection Agency (EPA) dispersion calculation method is widely accepted throughout the world, it is the basis for the method included here. The US has led in the development of dispersion calculation methods for permitting of industrial facilities that emit the so called **criteria pollutants** (i.e., sulfur dioxide, particulate matter, nitrogen dioxide, carbon monoxide, and ozone) with the 1977 Clean Air Act Amendments (CAAA) and ensuing regulations. These regulations forced a reliance on dispersion calculation methods to a much greater extent than previously, and at the same time, restrict the number and type of calculation procedures acceptable for regulatory purposes. In the years that followed, most countries in which ExxonMobil has operations have accepted the dispersion calculation methods recommended by the EPA.

As the EPA led in the development of methods for the dispersion of criteria pollutants, the Europeans have lead the development of dispersion calculation methods for predicting the dispersion of accidental releases of heavier-than-air gases. Major releases of flammable and toxic gases in Europe motivated this development as well as the original Seveso Directive. With the Bhopal disaster, the US included accidental release provisions in the 1990 CAAA. Also, the European Union (EU) has replaced the Seveso Directive with a new directive known as the Control Of Major Accident Hazards (COMAH). Through this legislation in the US and EU, further reliance is expected on dispersion calculation methods for assessing accidental hazardous releases.

Because of regulatory constraints and the technical complexity of actual problems, users of this section will frequently require assistance either from EMRE's Environmental Engineering Section or from a qualified outside consultant. As a general rule, a user should consider asking for help, even if they are somewhat knowledgeable about dispersion calculations. This is especially important if the calculated results and the allowed maximum concentrations are the same order of magnitude (i.e., it is not absolutely clear-cut that the facility either complies or does not comply with the ambient criterion).

4 DEFINITIONS OF AIR POLLUTION AND ITS DISPERSION

In this section, when an important term is first introduced, it is shown in boldface.

4.1 NORMAL UNITS IN AIR POLLUTION

Air pollution concentrations are usually expressed in units of mass of pollutant per volume of contaminated air, e.g., $\mu\text{g}/\text{m}^3$ (nlbm/ft^3). If the contaminant is a gas, the concentrations may also be expressed in units of volume of pollutant per volume of contaminated air, e.g., cm^3/m^3 or the equivalent volume parts per million (vppm). Volume/volume units have the advantage in that they are independent of temperature. [Table 2](#) gives factors for converting from one set of units to the other.

Two specific concentrations of interest are the **ambient concentration** and the **ground level concentration** (glc). Though both terms are commonly used interchangeably, they are not identical. An ambient concentration is the concentration at any point of interest in the atmosphere. Ambient concentrations at points on or close to the ground due to all sources are glcs.

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4.2 AIR POLLUTION SOURCES

Any substance discharged into the atmosphere from an air pollution source is an **emission**. A **point source** is one from which emissions of waste gas are discharged into the atmosphere through a well-defined conduit, and for which the downwind distance of concern is much larger than the conduit diameter. Most point sources are conventional flue gas stacks. A typical or ordinary industrial stack is usually characterized as one for which:

- The minimum height to avoid ambient turbulence effects near the ground is typically above about 15 m (50 ft) while the maximum height can be limited by regulation.
- The emissions are constant and continuous over a time period that is long with respect to both the time over which the concentrations are measured and averaged, and the downwind distance of concern divided by the wind speed.
- The stack exit velocity is high enough with respect to the mean horizontal wind speed (at least 1–1/2 times) so that the pollutant plume is not sucked into the low-pressure region on the lee side of the stack.
- The emissions are discharged at temperatures less than about 550°C (1000°F) and at exit velocities less than about 40 m/s (130 ft/s).
- The average molecular weight of the emitted stream is close to that of air (28.97).

Process vents, safety valves, and tank vents are other point sources in process facilities. Typically, these sources have shorter stacks and emit streams that are significantly different than air. Also, exit (exhaust) velocities can be either much higher or lower than the velocities from conventional flue gas stacks, and release durations are short rather than constant and continuous.

An **area source**, unlike a point source, does not emit pollutants through a well-defined conduit nor does the downwind distance of concern have to be larger than the area of the source. Frequently, even if a source is known to be emitted from individual points, it is considered to be an area source if the points are too numerous to consider individually or it is otherwise convenient to do so for the sake of calculation. Here, emissions are assumed to be discharged from the same elevation. A **volume source** is generally a combination of numerous point sources of different height. It represents a convenient mathematical construct to calculate dispersion for complicated sources. **Fugitive emissions**, usually treated as either an area or volume source, result from leaks in pollution control devices and other mechanical equipment. Blow-off from stored piles of crushed or ground solids is another example of fugitive emissions. Such emissions are usually not amenable to dispersion calculations using simple techniques. Consult the Environmental Engineering Section of the EMRE Plant Engineering Division or a qualified outside consultant for guidance.

4.3 REGULATORY TERMS

Ambient Air Quality Standards (AAQS) are those ambient air pollution concentrations, usually glcs, that a regulatory agency has decreed may either never be exceeded or may be exceeded only a certain, small percentage of the time. AAQS are intended to protect the public health and welfare. The current **National AAQS (NAAQS)** for the US and several other countries is listed in [Table 1](#). AAQS represent the maximum total allowable contributions of pollution from all sources. These include natural and anthropogenic sources (i.e., stationary and mobile).

The aim of regulatory agencies is to keep or bring ambient concentrations below the AAQS. Countries use different regulatory approaches to achieve this goal. For example, some AAQS promulgated represent the maximum allowable ambient ground level concentration for a given new or modified facility. This approach is not used in the US. In the US, regulatory authorities require a facility to demonstrate that it will raise existing ambient ground level concentrations by only a small portion of the total NAAQS. Further, many other restrictions and limitations are contained in US regulations. Because regulations differ between countries, specific guidance should always be obtained from the appropriate regulatory authority prior to conducting any facility compliance demonstration. This will ensure consistency with country-approved regulations.

Sometimes, before a new or modified air pollution source is allowed to begin operations, the owner must decrease pollutants from other nearby sources so that the net increase in emissions is zero or even negative. The decreased emissions, or **emissions offsets**, can occur at sources belonging to a different owner than the owner of the new or modified source. Usually, but not always, emission offsets are required only for pollutants whose existing ambient concentrations exceed applicable air quality standards.

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For fugitive and accidental releases of hazardous substances, regulations often require **hazard assessments**. It is part of a quantitative risk analysis that estimates the downwind ambient concentrations for releases, and can be compared to ambient chronic or acute criterion. For chronic hazard assessments, continuous emissions of substances that are known to cause long-term health effects are calculated using conventional dispersion methods. For acute hazard assessments, accidental releases resulting from equipment failures are analyzed using dispersion methods developed for releases of substances in which heavier-than-air gas clouds are produced. Typically, acute hazard assessments are concerned with acutely toxic and flammable substances.

5 BASIC AIR POLLUTION METEOROLOGY

Air dispersion, or **atmospheric diffusion**, is the dilution of an air pollutant due to natural atmospheric movement and to the interaction between the momentum and buoyancy (if any) of the pollutant and natural convective mixing of the atmosphere.

The atmosphere is constantly moving in all directions and on all size scales. For convenience, the average of the larger-scale slowly changing component is termed the **mean wind speed**, **u**, while the rapidly changing smaller-scale components are called **turbulence** and is treated statistically. Both are actually on one continuous spectrum. For air dispersion calculations, the assumption is usually made that the mean wind speed is purely horizontal (the vertical component is zero), and that turbulence is a totally random phenomenon. Nearest the ground, turbulence is caused by air convection and by mechanical mixing as the wind passes over and around natural and man-made surface obstructions. **Surface roughness length** is a measure of the mechanical turbulence. Plume dilution increases with increasing turbulence. Note that the wind (speed and direction) changes with elevation. This is called **wind shear**. When calculating air dispersion, the change of wind direction is almost never considered. However, the change of wind speed is normally taken into account by assuming an exponential increase with elevation. The often-used EPA method is the logarithmic wind speed power law as follows:

$$u_z = u_m (z / z_m)^p \quad \text{Eq. (1)}$$

where:	u_z	=	Wind speed at elevation z , m/s (ft/s)
	u_m	=	Wind speed at reference elevation, z_m , m/s (ft/s)
	z	=	Desired elevation at which wind speed is to be calculated, m (ft)
	z_m	=	Reference elevation, m (normally 10 m) (~33 ft)
	p	=	Empirically derived wind speed exponent (Table 3)

Constant turbulence means that air pollution concentrations are always changing, and the highest measured concentrations increase as the averaging time decreases. **Averaging time** is the time interval over which the concentration is measured, and can vary from a fraction of a second (the response time of very fast instruments - there are no instantaneous measurements) up to a year or more. It has been found that, for non-reactive pollutants and sampling points not located between two or more sources of interest, the highest concentrations generally vary with averaging time according to the formula

$$(\chi_1 / \chi_2) = (t_1 / t_2)^{-\alpha} \quad \text{Eq. (2)}$$

where:	χ_1	=	Highest glc over averaging time t_1
	χ_2	=	Highest glc over averaging time t_2
	α	=	Conversion exponent = 0.2

Calculated maximum concentrations may be converted from one averaging time to another (up to 24-hour averages) using this equation. For approximate estimates of annual average concentrations, a reasonable rule of thumb for the annual concentration value is about 10% of 1-hour maximum concentrations.

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5.1 ATMOSPHERIC STABILITY

Throughout the day, the dispersive capacity of the atmosphere changes as solar radiation and wind speed change. **Atmospheric stability** describes the dispersive capacity of the atmosphere in terms of convective and mechanical turbulence. To calculate pollutant dispersion, it is necessary to characterize this dispersive capacity of the atmosphere. However, the dispersive capability is hard to measure. What is done in practice is to define atmospheric stability by empirical or semi-empirical means based on easily observed phenomena, and then to use the stability so defined as an indicator of dispersive capability. Unfortunately, several empirical definitions of stability exist, and they are not consistent with each other. Also, the continuous turbulence spectrum of the atmosphere is frequently divided into discrete stability categories, and the several schemes that exist for doing this are not consistent with each other. Most schemes consider 4 or 6 discrete stability categories (more rarely 7 or some other number) with the designation "A" (or "1") going to the most unstable atmosphere and subsequent letters (or numbers) indicating progressively more stable atmospheres. **Neutral atmospheres** are usually indicated by "C" or "D" ("3" or "4"). Note that the term "neutral atmosphere" does not denote zero dispersion. All atmospheres, even those more stable than neutral, disperse pollutants, although an extremely stable atmospheric layer (e.g., a layer associated with an inversion) can be impenetrable to a dispersing layer. By this approach, the local dispersive capability of the atmosphere defines the local stability.

One way of defining divisions of the turbulence spectrum into stability categories is by means of the **vertical temperature gradient** or **lapse rate**, Γ . This is the rate at which atmospheric temperature decreases with elevation from the ground. In this scheme, an **adiabatic lapse rate** is defined as neutral. This is the change in temperature with height of a small volume of air rising in the atmosphere and expanding adiabatically as the pressure decreases (note: an adiabatic process is defined as one where a material changes its physical state (i.e., pressure, volume, or temperature) without any heat being either added to it or withdrawn from it). It is numerically equal to -0.0098°K/m ($-0.55^\circ\text{F}/100\text{ ft}$); the negative sign indicates decreasing temperature with increasing altitude). If the air temperature decreases more rapidly with height, the lapse rate is **super-adiabatic** and the atmosphere is unstable. If the air temperature decreases more slowly or even increases with height, the lapse rate is **sub adiabatic** and the atmosphere is stable. For convenience, meteorologists have defined a **potential temperature gradient**, $d\theta/dz$, whose value is zero when the atmosphere is neutral, i.e., the potential temperature gradient is the actual temperature gradient minus the adiabatic lapse rate (the actual temperature gradient plus $0.55^\circ\text{F}/100\text{ ft}$ or 0.0098°K/m). Because the adiabatic lapse rate is subtracted out, temperature differences due to pressure gradient are eliminated. The potential temperature gradient reflects only differences due to heat imbalances, and is zero for neutral atmospheres, positive for stable atmospheres, and negative for unstable atmospheres.

Other definitions of atmospheric stability related to temperature gradient, are the **Richardson number**, which is the ratio of the buoyant forces caused by the lapse rate to the acceleration forces caused by wind shear and from boundary layer similarity theory, the **Monin Obukhov length** (L), which is the ratio of the fluctuating component of the wind to the atmospheric heat flux. The absolute value of the Monin Obukhov length can be thought of as the depth of the mechanically mixed layer near the ground. L is positive for stable conditions (usually at night), negative for unstable (usually daytime under clear skies), and approaches infinity for neutral conditions (dawn and dusk transitions periods and cloudy windy conditions).

A commonly used definition of atmospheric stability, unrelated to and frequently inconsistent with temperature gradient, etc., is the definition by means of solar insolation (i.e., whether it is day or night and whether it is sunny or cloudy) and wind speed. The six **Pasquill stability categories** ("A" through "F") are defined in this way. [Table 4](#) presents the Pasquill-Turner allowed combinations of wind speed and atmospheric stability for rural areas (i.e., areas consisting of mostly flat, vegetated terrain). The corresponding atmospheric stability categories in an urban area are generally one or two categories more unstable than would be predicted using the Pasquill-Turner approach. In the EPA computer programs, specific dispersion coefficients have been recommended for rural and urban areas.

The selection of rural or urban coefficient is often decided by using the **Auer scheme** for many regulatory applications. In its simplest form, if more than 50% of the area within a 3 km (~2 miles) radius of the emission source is vegetated, the area is considered rural. Otherwise it is urban. In more recent computer programs, such as AERMOD and ADMS 3 from the US EPA and the UK Meteorology Office, respectively, as well as programs for accidental releases of heavier-than-air gases (e.g., PHAST), the surface roughness length must be specified to account for the influence on dispersion of surface obstructions in the surrounding area. Here, it is assumed that the plume is always large in comparison to height of the surface obstructions. Typical surface roughness lengths for various ground conditions are shown in [Table 5](#). Surface roughness length, z_0 , is effectively the height above the surface of the ground at which the mean wind speed, u , is equal to zero.

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Finally, many regulatory agencies insist on a thorough consideration of atmospheric stability and wind speed conditions in performing air dispersion calculations. This may require the gathering and utilization of hourly sequential meteorological data or the use of representative combinations of wind speed and atmospheric stability. It is always preferable to use on-site meteorological data when available, as it produces more accurate estimates of glcs. However, often meteorological data from a nearby location such as an airport, etc., are substituted. Using representative combinations of wind speed and atmospheric stability is the least accurate and most conservative alternative. When hourly sequential meteorological data are not available, recommended combinations of wind speed and stability can be used ([Table 6](#)).

5.2 ATMOSPHERIC INVERSION CONDITIONS

Inversion conditions occur in the atmosphere near the ground and aloft. An inversion is a layer of air in the atmosphere in which the temperature increases with height rather than decreasing with height. Near the ground, diurnal variations typically cause them as well as their break-up. Aloft, it can be an impenetrable layer to plume dispersion. An elevated inversion is often called an **inversion lid** or a **capped inversion**. The height of the inversion lid is called the **mixing height**. Elevated inversions often persist for days or even weeks at a time. Inversions can strongly restrict pollutant dispersion and during break-up can cause high short-term glcs.

At the ground, a **surface inversion layer** is typically formed at night under conditions of light wind and clear skies, when the loss of heat from the ground cools the air adjacent to it faster than the air aloft. At dawn, solar heating begins warming the ground producing an unstable air mass near the ground that pushes the more stable layer aloft. As the stable surface layer is initially below the height of the plume, pollutants from elevated stacks are trapped above the inversion resulting in no glc. As the depth of the unstable air mass grows, it reaches the height of the plume. Then, the pollutants are rapidly mixed (**fumigated**) in the unstable air mass, perhaps all the way to the ground, causing short term, high glcs. Elevated inversions are more common. In an **elevated inversion** the air temperature decreases with height from the ground to the base of the elevated inversion layer. Then, the temperature increases with height through the depth of air aloft to the top of the layer. Above the inversion, the temperature returns to the normal decrease of temperature with height. This condition can be caused by the gradual descent of air aloft accompanied by adiabatic warming from an increase in atmospheric pressure, by a sea breeze introducing a layer of cool air beneath a warmer air mass, or by the passage of a weather front. A method for calculating glcs for inversion break-up is provided in [Equation \(15\)](#). In [Figure 1](#), simplistic sketches are presented of elevated plume behaviors under various atmospheric stabilities and mixing height conditions. In the small diagram of altitude versus temperature, the atmospheric condition conducive to plume formation is shown in terms of the relation between the existing ambient temperature gradient (solid lines) and the dry adiabatic lapse rate (dashed lines).

5.3 PLUME RISE

Plume rise (Δh) is the rise of a waste gas plume in the atmosphere due to its buoyancy or momentum. Essentially, the higher the plume rise the lower the glcs. Most calculation methods for plume rise treat it as if it were independent of dispersion. Since it is not, plume rise is usually better regarded as a convenient mathematical construct rather than an accurate description of reality. When the plume rise is added to the stack height (h), the result is called the **effective stack height (H)**.

$$H = h + \Delta h \quad \text{Eq. (3)}$$

For most applications and for nearly all regulatory purposes, the plume rise formulas by Briggs are favored. These formulas are based on theoretical considerations and observations of plume rise from a wide variety of sources. Separate formulas are used for buoyancy and momentum induced rise for various atmospheric stability conditions. The first step in calculating plume rise is to calculate the buoyancy flux factor, F in units of m^4/sec^3 (ft^4/sec^3):

$$F = [g (V_s) (d^2) (\Delta T)] / [4 T_s] \quad \text{Eq. (4)}$$

where: g = Acceleration of gravity, 9.8 m/sec^2 (32.2 ft/sec^2)
 ΔT = $T_s - T_a$, T_s is the stack gas temperature, $^{\circ}\text{K}$ ($^{\circ}\text{R}$), and T_a is the air temperature, $^{\circ}\text{K}$ ($^{\circ}\text{R}$)
 V_s = Stack gas exit velocity, m/sec (ft/sec)
 d = Inside stack diameter, m (ft), at the release point to the atmosphere

In order to determine whether the plume is dominated by buoyant or momentum rise, the critical temperature difference, ΔT_c , is calculated based on the atmospheric stability.

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Unstable or neutral atmospheres:

$$\text{For } F < 55 \text{ (6366 ft}^4\text{/s)} \quad \Delta T_c = [(0.0297) (T_s) (V_s^{1/3})] / [d^{2/3}] \quad \text{Eq. (5)}$$

$$\text{For } F \geq 55 \text{ (6366 ft}^4\text{/s)} \quad \Delta T_c = [(0.00575) (T_s) (V_s^{2/3})] / [d^{1/3}] \quad \text{Eq. (6)}$$

Stable atmospheres:

$$\Delta T_c = [(0.01958) (T_s) (V_s) (S^{1/3})] \quad \text{Eq. (7)}$$

where:

S	=	$g(dT/dz - \Gamma)/T_a$
Γ	=	Adiabatic lapse rate (-0.0098 °K/m, -0.0054 °R/ft)
dT/dz	=	Actual temperature gradient (0.0102 °K/m or 0.0056 °R/ft for "E" and 0.0252 °K/m or 0.014 °R/ft for "F" stability)

If the actual ΔT exceeds ΔT_c , the plume is buoyant dominated; if not, it is momentum dominated. The appropriate equation for calculating the plume rise, Δh , is then selected from [Table 7](#).

5.4 STACK TIP AND BUILDING DOWNWASH

Aerodynamic downwash (commonly known as stack-tip, building, or terrain downwash) is the sucking down of a plume into the low-pressure cavity on the lee side of a bluff body (building or hill) nearby the stack. **Stack tip downwash** can generally be avoided by making the stack exit velocity at least one and a half times the ambient horizontal wind speed. If the stack exit velocity is very low, downwash (or down draft) may result instead of plume rise. Building and terrain downwash can generally be avoided by constructing a taller stack than the nearby obstruction. The stack height that is normally sufficient to prevent building or terrain downwash is called **good engineering stack height**,

$$H_g = B_h + 1.5L \quad \text{Eq. (8)}$$

where:

H_g	=	Good engineering stack height, measured from the ground-level elevation at the base of the stack
B_h	=	Height of nearby structure measured from the ground level elevation at the base of the stack
L	=	Lesser dimension, height or projected width, of the nearby structure

In [Eq. \(8\)](#), both the height and width are determined from the frontal area of the structure, projected onto a plane perpendicular to the direction of the wind. For the purpose of determining good engineering stack height, **nearby** is limited to five structure heights or widths, whichever is less, downwind from the trailing edge of the structure. The area of influence becomes diminishingly smaller as the height to width ratio of a structure increases. Therefore, an isolated and thin process tower should not be considered in good engineering stack height determinations. In areas with multiple towers and process structures, computer models are necessary to calculate good engineering stack height. Also, as process structures and towers are generally aerodynamically smooth and porous, [Eq. \(8\)](#) should be used with caution. Here, rule of thumb guidance is to calculate H_g using the dimensions of the solid portion of the structure that is enclosed by latticework. However, rigorous techniques using an environmental wind tunnel may be necessary to justify taller stacks to regulatory authorities in some cases. In this latter situation, assistance can be obtained from EMRE's Environmental Engineering Section or a qualified outside consultant.

6 MODELS, METHODS, AND COMPUTER PROGRAMS

A **model** is a description of physical phenomena; a **method** is a specific set of equations conforming to a particular model, including all the constants necessary to obtain numerical results; and a **computer program** is an algorithm for solving the equations on a computer. For example, there is the **Gaussian model**, which states that plume concentrations downwind of a stack are normally distributed both horizontally and vertically. There is the EPA method, which incorporates specific numerical values for the standard deviations of these normal distributions, and also a specific equation to calculate plume rise and effective stack height. Finally, there are computer programs such as the AMS/EPA Regulatory Model (AERMOD), the Industrial Source Complex (ISC3), and the SCREEN3 codes from the US EPA, which solve the equations. AERMOD and ISC3 are **refined** regulatory computer programs, while SCREEN3 is a simple **screening** computer program. Both ISC3 and SCREEN3 use the Gaussian model for dispersion. AERMOD uses the Gaussian model for stable wind conditions, but uses a non-Gaussian probability density function for vertical dispersion and unstable wind conditions. It also uses more modern approaches to account for the Planetary Boundary Layer (PBL).